CERES Terra Edition2C/Aqua Edition2B SYN/AVG/ZAVG Computed surface and TOA fluxes based on GEO cloud properties - Accuracy and Validation

Introduction

This section discusses quality of the geostationary (GEO) cloud properties and fluxes that that are used as input in the Fu-Liou radiative transfer modeled fluxes as computed by the CERES Surface and Atmospheric Radiation Budget (SARB) Working Group. The section does not directly validate the SARB radiative transfer algorithm, which was developed and optimized to produce instantaneous computed fluxes using MODIS clouds, GEOS-4 meteorology, and MATCH aerosols, which were tuned to the CERES TOA measured fluxes to provide fluxes consistent with CERES fluxes. Rather this section discusses the quality of the AVG/ZAVG diurnally averaged monthly mean fluxes. Many regions have diurnal dependent flux variations such as maritime stratus regions (for example off the coast of Peru). In order to account for diurnal variation between the CERES measurements times, the cloud properties are retrieved from 3-hourly geostationary (GEO) images, similarly to ISCCP but using a subset of the multi-channel MODIS CERES (not the MOD0 Goddard products) retrieval algorithm. These cloud properties are inferior to the MODIS retrievals since they are retrieved using only the visible (0.65µm) and IR (11µm) channels from 5 geostationary satellites, however the cloud properties can be sampled every 3 hours or 8 times a day, a much greater frequency then twice daily from Terra (10:30AM) sun-synchronous satellite. This section evaluates the SARB computed fluxes from the merged MODIS and GEO diurnal cloud properties to improve the 3-hourly daily (SYN) and monthly mean (AVG, ZAVG) computed fluxes. The validation presented shows that the GEO cloud properties and fluxes improve the SARB diurnally averaged computed fluxes over assuming constant meteorology between MODIS retrievals and are of climate quality. These fluxes and can be compared directly with monthly climate model output.

The SYN/AVG/ZAVG monthly mean fluxes are derived from hourly instantaneous computations during the course of the month. The cloud properties and TOA fluxes are from the SRBAVG-GEO temporal interpolation algorithm. For a given hour increment, the cloud input source is prioritized as follows, CERES/MODIS measurement, GEO measurement, and temporally interpolated. For a single CERES satellite product most hourly flux computations are based on GEO clouds. These GEO computed fluxes can be validated against independent surface radiometers, Terra merged with GEO compared with Aqua measurements, and Geostationary Earth Radiation Budget (GERB) 15 minute observed fluxes over the Meteosat geostationary domain. Since the GEO cloud properties are not normalized to MODIS and are sensitive to GEO calibration drifts, which may be interpreted as natural variability, an EOF analysis will be performed to detect any GEO cloud artifacts. Unlike MODIS, which has an onboard solar diffuser, to monitor visible calibration stability, GEO visible channels do not have onboard calibration and must be calibrated vicariously. The CERES project calibrates the GEO visible channels against MODIS using coincident matches. Further information can be obtained in the SRBAVG Data Quality Summary. The validation is organized into 3 parts, (1) surface, (2) Terra vs. Aqua, (3) GERB flux comparisons.

Surface Flux Comparisons

Surface radiometer measurements provide an independent broadband fluxes to compare the accuracy of computed surface flux datasets. The SYN/AVG/ZAVG computed surface fluxes are an improvement over existing datasets. First the GEOS-4 atmospheric input algorithm is frozen, so that improvements will not be interpreted as natural variability. The cloud properties are based on multi-channel MODIS and GEO retrievals. Lastly, the GEO cloud properties are based on stable calibration against MODIS. The AVG monthly untuned surface fluxes were compared with ECMWF ERA40, ISCCP FD, GEWEX SRB 3.0, CERES ModelB, which is the parameterized surface flux available on the CERES SRBAVG product. The differences of the cloud and atmosphere inputs of the various datasets are noted in Table 1. The seasonal months beginning with April 2000 and ending with October 2005 were compared against diurnally averaged 23-site surface fluxes as prepared by the CERES SARB group and are available on the CAVE web site. 23 surface sites were selected based on data availability, radiometer accuracy, and proximity from other surface sites, in order to optimize global distribution and are shown in Fig. 1. The numerous SGP sites are removed from the database. Note that the surface sites are mainly land based and do not represent a majority of earth's oceans. The monthly mean 1° gridded computed surface flux is compared with the time integrated surface site radiometer flux.

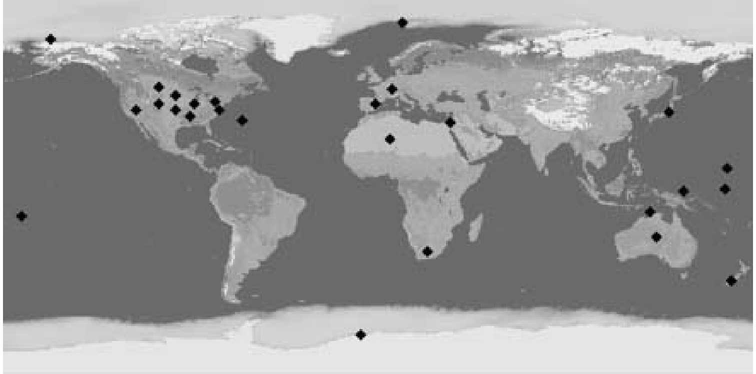

Fig. 1. *The 23 surface sites used in the July 2004 hourly surface flux comparisons*

Table 2 shows the computed monthly mean surface flux differences according to dataset. Note the Terra or Aqua AVG tuned or untuned sigma (RMS error after removing the bias) SW down reduction compared with other datasets is almost 50%. The CERES-SRBAVG ModelB fluxes use the same input as AVG, however they use a global parameterization, which may not be optimized for a particular surface site, such as over polar regions. For SW up the AVG is comparable to the other datasets except SRB and ModelB. In the LW the AVG RMS is comparable to SRB and ModelB and 50% of the ISCCP FD product. The LW surface fluxes are mainly dependent on the atmospheric profile near the surface and skin temperature. The datasets using GEOS-4 have very similar LW RMS statistics. The CERES TOA fluxes and cloud properties that improved the AVG SW fluxes have less of an impact on the surface LW fluxes, since they are decoupled from most of the atmosphere. The monthly mean RMS is essentially accesses the datasets ability to capture the seasonal surface flux variation. Based on previous CRS studies the greatest improvements of the AVG over other datasets is in polar regions, where MODIS based cloud properties, have improved the computed surface fluxes. For polar regions only MODIS cloud properties are used, since the GEO extent is ±60° latitude, and the Terra and Aqua based clouds are similar. The island sites present the greatest RMS errors, since the island microclimate may not represent the 1° region, such as island based cloud effects.

Table 1: Surface dataset input comparison

Dataset	ISCCP-FD	SRB	Model-B	CERES
Clouds	ISCCP	ISCCP	MODIS/GEO	MODIS/GEO
Profile	TOVS	GEOS-4	GEOS-4	GEOS-4

Table 2: 23-site surface flux dataset comparison based on seasonal monthly means

Surface Mean (Wm^{-2})	SWdown 188		SWup 42		LWdown 334		LWup 380	
	Bias	**Sigma**	**Bias**	**Sigma**	**Bias**	**Sigma**	**Bias**	**Sigma**
ECMWF	-4.9	23.8	-9.5	21.8	-0.4	14.3	-0.9	13.9
ISCCP-FD	-1.0	20.6	-15.6	20.5	7.1	20.6	0.3	22.5
SRB	-2.9	22.4	-18.4	29.9	-0.9	11.2	-2.7	13.9
Model B	0.5	24.0	-15.7	32.4	-0.5	10.3	-7.6	15.4
Terra untuned	4.4	12.3	-13.1	21.8	-5.2	10.4	-5.6	16.4
Aqua untuned	3.3	9.8	-14.7	21.6	-5.6	10.4	-5.3	16.4
Terra tuned	4.6	12.4	-13.1	21.6	-5.2	10.3	-5.0	15.9
Aqua tuned	3.7	9.9	-14.5	21.6	-5.5	10.4	-4.8	15.9

The effects of tuning to the TOA flux on the computed surface fluxes

The advantage of using SYN/AVG/ZAVG "tuned" fluxes is that the cloud properties, meteorology and computed TOA fluxes are consistent with the CERES TOA measured fluxes. This will allow a better understanding of the atmosphere's energy budget. In order to "tune" the computed TOA fluxes so that they better match the CERES measurements, minimal cloud property adjustments are performed to achieve maximum computed flux differences. For cloudy skies, the cloud top height, optical and amount are adjusted within their natural uncertainties to match both the SW and LW CERES TOA flux. The tuning process is a non-iterative approach and relies on apriori uncertainties, since computing fluxes is very computer intensive. These cloud property adjustments will effect the computation of the surface fluxes as well as atmospheric and TOA fluxes. The SARB algorithm tunes the atmospheric, surface and aerosol properties using the clear-sky flux. The computed cloud and clear-sky fluxes are then combined for the all-sky flux.

The hourly-untuned fluxes are then tuned to the SRBAVG-GEO (merged CERES and GEO) TOA product fluxes. Table 2 shows the tuning effect on the SWup, SWdn, LWup and LWdn surface monthly mean fluxes. Table 2 indicates very little difference between the untuned and tuned monthly mean surface fluxes. The tuning process seems to have very little impact on computed surface fluxes. This was expected in the LW, since the LW surface fluxes are decoupled from the TOA and most of the atmosphere. Although the tuning process did not improve the surface SW fluxes, it did not reduce the quality either.

Perhaps the differences are more apparent at the hourly computation level, rather than at the monthly level. For this validation the computed fluxes are examined at the hourly level. The surface site instantaneous fluxes are averaged hourly. For July 2004 all the 744-hourly 23-site surface tuned and untuned fluxes were compared with the SRBAVG-GEO (merged CERES and GEO) TOA fluxes. The untuned and tuned TOA SW rms is 25 (22%) and 13 Wm^{-2} (12%) respectively. The tuning process reduced the measured and computed flux difference by ~50% at the TOA However the comparison of SWdown at the surface, the hourly rms is 68 Wm^{-2} (31%) for both untuned and tuned fluxes. There were no changes in the SWup, LWdown or LWup either. Again the impact of tuning in adjusting the cloud properties did not affect the surface computed fluxes.

The impact of using GEO clouds between MODIS measurement times on computed surface fluxes.

This validation assesses the improvement of the computed surface fluxes of using 3-hourly GEO clouds between the 12-hourly MODIS measurement times, rather than assuming linearly changing MODIS cloud properties. The AVG product input uses the SRBAVG merged MODIS and GEO cloud and fluxes referred to as SRBAVG-GEO product. As shown in the SRBAVG Data Quality Summary, the SRBAVG-GEO diurnally averaged monthly means are more robust then the SRBAVG-nonGEO (CERES only) TOA fluxes, since they take into account the changing meteorology between CERES measurements on sun-synchronous orbits. The Terra and Aqua orbits observes a given region twice daily at 10:30 (AM/PM) LT and 1:30 LT respectively at the equator. The GEO cloud and fluxes have improved the monthly mean TOA fluxes, however, do they also improve surface fluxes? The inclusion of GEO clouds is a trade off between using GEO cloud properties, which are inferior to MODIS clouds, and having observed meteorology information between MODIS measurements.

For this validation July 2004 hourly computed surface fluxes are compared to the same 23 surface sites. The SARB computed flux algorithm is performed twice, first the standard SYN/AVG/ZAVG product fluxes, which are the merged MODIS and GEO cloud properties, referred to as in the statistics as "MERGED" and second the MODIS-only temporally interpolated cloud property computed fluxes, named "MODIS-only". The hourly computations from each dataset can be divided as derived from either MODIS (M), GEO (G) or interpolated (I) cloud properties. Table 3, shows the typical diurnal distribution of the clouds and fluxes from either the "merged" or "MODIS-only" datasets. The 2 cyan hourboxes represent MODIS observed; the 8 GEO hourboxes are displayed in green. Each hourly flux is based on the hourly GMT time increments that are centered on the half hour. Note that some MODIS-only interpolated hourboxes can be as much as 5 hours removed from the nearest measurement. The all-sky Model-B parameterized fluxes are also derived from both datasets. The Model-B fluxes can also be used as a baseline to determine the benefit of computation versus parameterization of estimating surface fluxes, since the computation requires more resources.

Table 3: The sampling pattern for the merged (MODIS+GEO) diurnally complete and MODIS-only Terra (10:30 LT) datasets

Hour+:30	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Merge	G	I	I	G	I	I	G	I	I	G	M	I	G	I	I	G	I	I	G	I	I	G	M	I
MODIS	I	I	I	I	I	I	I	I	I	I	M	I	I	I	I	I	I	I	I	I	I	I	M	I

Table 4 shows the SW down and LW down surface flux comparison. The statistics are shown from Terra, however the Aqua statistics are similar. Using the SARB (untuned) surface flux computations reduces the SW down flux RMS error by ~10% over parameterization (Model B), whether using the merged or MODIS-only datasets. Also using the merged dataset reduces the SW down flux RMS error ~10% over using the MODIS-only dataset. The GEO clouds have also reduced the SW down bias. Table 4 shows the LW down flux comparison. There is little change in the RMS error between the merged and MODIS-only datasets, which is not surprising, since the LW surface fluxes are mainly a function of the lower atmosphere. Perhaps the cloud base height differences could impact the surface computations, but apparently not. In this case, the LW parameterized surface fluxes are similar to the computed fluxes. Again indicating that cloud properties have a minor role in computing the LW down. Also SW up and LW up show no improvement (not shown), whether using merged or the MODIS-only dataset.

Table 4: Comparison of the 23-site surface computed and measured fluxes for July 2004

Terra Surface (%)		SWdown (surface-untuned)		LWdown (surface-untuned)	
Dataset		Bias	RMS	Bias	RMS
Model-B	MODIS	3.2	41	0.0	6.1
	merged	1.8	36	0.0	6.1
Untuned	MODIS	3.2	37	-2.0	5.9
	merged	2.8	32	-1.4	5.9

Table 5 shows the comparison between the MODIS, GEO, Interpolated computed fluxes compared with the corresponding 23 surface site hourly fluxes for July 2004. For SW down the MODIS multi-channel cloud properties have an RMS error of 22%, whereas the 2-channel GEO cloud retrievals have a RMS error of 31%, indicating the inferior GEO cloud retrievals. Linearly temporally interpolated "merged" cloud properties, have similar RMS errors as GEO clouds. However the CERES temporally interpolated cloud properties have greater SW down flux RMS errors then either the GEO or GEO interpolated clouds. The further the interpolated hour is temporally from the nearest observation time the greater the RMS error. The interpolation never exceeds one hour in the merged dataset, since it incorporates 3-hourly GEO measurements. Introducing GEO cloud properties is adding value to the diurnally computed SW down fluxes. The variation of the surface flux biases need to be better understood and are probably the result of a few individual sites. The SW up, LW down and LW up surface fluxes show no improvement using the merged dataset. Also the Aqua based results are similar to the Terra (not shown).

Table 5: Comparison of the 23-site surface computed and measured fluxes for July 2004 as a function of the cloud source

Terra Surface (%)	SWdown (surface-untuned)		LWdown (surface-untuned)	
	Bias	**RMS**	**Bias**	**RMS**
MODIS	3.1	22	-0.9	7.0
GEO	2.2	31	-1.6	5.5
Interp-CERES	2.2	37	-2.0	6.3
Interp-merge	2.9	32	-1.4	5.7

Combining the 23-sites has probably dampened the individual site diurnal flux cycle. To determine the impact of GEO clouds for a region with diurnally varying clouds, the ARM-SGP (Atmospheric Radiation Measurement - Southern Great Plains) sites are used during July 2004. For this domain over the US states of Oklahoma and Kansas, there is a diurnal cycle, where in the morning it is clear and in the afternoon convection develops. To determine the effectiveness of GEO clouds, the daylight hours were grouped into 4 local time increments, early morning (3-9AM), morning (6-12AM), afternoon (12-18PM) and late afternoon (15-21PM). The RMS error was computed for both datasets (merged and MODIS-only) for all hourly increments. The MODIS-only Aqua dataset has MODIS measurements at 13:30LT and the Terra dataset at 10:30LT. The SW down surface computed fluxes were compared with surface radiometer fluxes and the results are shown in Table 6.

Table 6: Comparison of SGP-only-sites surface SW down flux for July 2004 as a function of local time

SWdown (%)	Terra (10:30)		Aqua (13:30)	
Local Time	**MODIS**	**merged**	**MODIS**	**merged**
3-9	34	26	39	27
6-12	21	19	25	19
12-18	22	18	19	18
15-21	35	25	33	26

As expected the Aqua 12-18LT and Terra 6-12LT had comparable RMS errors, since the MODIS cloud properties were measured during these times. A slightly greater MODIS-only RMS was observed as compared with the merged dataset for Aqua 6-12LT and Terra 12-18LT was observed. For those time increments, the MODIS interpolated cloud properties are still within a few hours of the MODIS measurement time. The greatest RMS difference is observed in the early morning (3-9LT) and late afternoon (15-21LT) between the MODIS-only and merged datasets. There is more than a 4-hour time gap between the last MODIS measurement time. The MODIS-only clouds are linearly interpolated between day and night cloud properties, which do not take into the account the morning clearing or the late afternoon convection. The 3-hourly GEO cloud properties can reliably track the cloud property variations over time, although they are not as accurate as a MODIS cloud property retrieval. Again SW up, LW down and LW up showed no considerable difference between the merged and MODIS-only datasets.

The last surface analysis involving the merged and MODIS-only datasets is to determine whether tuning to the merged TOA fluxes improves the MODIS-only derived surface fluxes. Previous tuned and untuned comparisons with the merged dataset, indicated no improvement, therefore assuring that the merged dataset has consistent clouds and fluxes. However the merged TOA fluxes and MODIS-only cloud properties are inconsistent. In this case tuning to the merged TOA flux adjusts the MODIS-only cloud properties to be more consistent with the merged clouds. 4 datasets are compared to the July 2004 SW-down hourly surface 23-site fluxes. Untuned MODIS-only, Tuned MODIS-only to the merged TOA flux, Untuned merged, and tuned merged to the merged TOA fluxes had RMS errors of 79, 74, 68 and 68 Wm^{-2} respectively. For both tuned cases, the tuning was performed with the merged TOA flux. The mean SW down flux was 224 Wm^{-2}. If the clouds and TOA fluxes are consistent (untuned merged dataset) the tuning has no impact. However if the clouds and TOA fluxes are inconsistent, such as untuned MODIS-only and merged TOA fluxes, the tuning redistributes the MODIS-only cloud properties more closely to reflect the merged TOA fluxes. Although the tuning did reduce the MODIS-only RMS error compared with unutuned, it did not remove the entire RMS error difference between the merged and MODIS-only datasets. Only the SW down showed significant improvement with tuning, the surface LW fluxes did not.

The consistency between Terra vs. Aqua computed fluxes

Another way to access the accuracy of the GEO derived computed fluxes is to compare them directly with time matched MODIS clouds. In this case the fluxes computed with MODIS clouds are considered as truth. It has been demonstrated in the SRBAVG DQS that the SRBAVG-GEO "merged" TOA fluxes are more consistent with coincident CERES TOA fluxes than the SRBAVG-nonGEO "MODIS-only" temporally interpolated fluxes. For these studies the Terra based temporally interpolated fluxes are compared with the coincident instantaneous observed (@13:30 LT) Aqua fluxes and the other way around.

To demonstrate this comparison, Fig 2 shows a typical maritime stratus region off the coast of Peru. In this region the stratus clouds are thickest in the morning and burn off through the day and are usually clear in the afternoon. One would expect the SW TOA fluxes to be greater in the morning then in the afternoon. If one assumes constant clouds throughout the day based on the Terra measurement time at 10:30LT the SW TOA flux is represented by the blue line and the measurement is the blue dot. CERES Directional SW flux models, which are a function of SZA, are used to estimate the flux during all other hourly increments during the day. The blue line overestimates the SW flux in the afternoon. The red line and dot identify the Aqua predicted and measured SW flux respectively based on constant clouds at 13:30LT. The red line underestimates the flux in the morning. At 13:30 LT the TOA SW flux difference between the Terra and Aqua fluxes is 100Wm^{-2}. The black line and dots represent the GEO predicted and derived TOA broadband (BB) fluxes, respectively The GEO based broadband fluxes are normalized to CERES, in this case Terra, in order to preserve the CERES calibration. However the Terra based GEO cloud products are not normalized to MODIS. As Figure 2 demonstrates the GEO derived fluxes are the most accurate diurnal fluxes. The flux difference between the Aqua and Terra at the Aqua measurement time is the MODIS-only dataset error. The flux difference between the GEO temporally interpolated and Aqua flux at the Aqua measurement time is the merged dataset error. One would expect the merged dataset to have smaller errors if the GEO fluxes and clouds are retrieved properly. Figure 3 shows the regional SW TOA rms error between the Aqua merged and MODIS-only tuned computed fluxes with Terra TOA measured at the Terra overpass time (10:30AM). Note the reduction in SW regional rms error between the merged and MODIS-only datasets, indicating the value the GEO derived BB TOA fluxes, especially in the tropics.

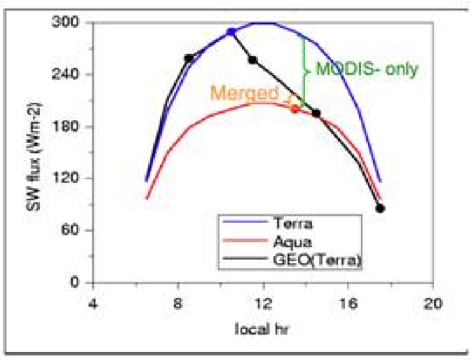

Fig. 2. *Plot showing the MODIS-only and merged TOA SW flux difference between Terra temporally interpolated and Aqua measured at 13:30PM*

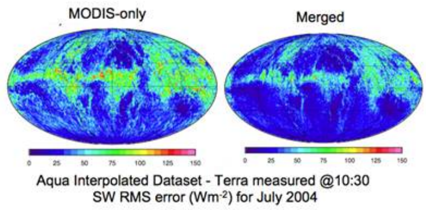

Fig. 3. *Comparison plot showing the MODIS-only and merged TOA tuned SW flux RMS error between Aqua temporally interpolated and Terra measured at 10:30AM for July 2004*

Table 7 completes that statistics shown in Figure 3. The "comp" column represents the method compared to the corresponding computed flux. The "measured" column refers to the method compared with the actual CERES TOA observed flux. Essentially the "comp" column indicates computed consistency with itself. The "measured" column indicates computed and CERES instrument measurement consistency. Aqua interpolated (Aqua-Interp) indicates the TOA temporally interpolated fluxes, where MODIS-only represents the SRBAVG-nonGEO product and merged the SRBAVG-GEO product. First, the computed consistency is better than computed and measured consistency. The MODIS-only datasets gains the greatest benefit from tuning. However the merged dataset has reduced the RMS by nearly 50% over MODIS-only indicating the value of GEO clouds and fluxes. Note the consistency between the method and the TOA measured flux (measured column). This indicates that the clouds and fluxes are consistent in the merged dataset, which is not the case with the MODIS-only dataset.

Table 7: Comparison of Aqua temporally interpolated and Terra measured (@10:30AM) SW and LW TOA fluxes

RMS (Wm^{-2})	Method	MODIS-only		Merged	
		Comp	Measure	Comp	Measure

			d		d
SW TOA	Aqua-Interp		56		29
	Untuned	39	55	22	31
	Tuned	28	39	20	29
LW TOA	Aqua-Interp		16		10
	Untuned	17	18	12	11
	Tuned	14	14	11	10

For the next study the computed surface fluxes from the merged and MODIS-only cloud database are compared with computed surface fluxes from measured MODIS clouds. The comparison is reveals the consistency in the computed fluxes between the MODIS and GEO clouds. The same is done for the ModelB surface fluxes to determine the added benefit of computations over parameterization. Results are shown in Table 8. Again the GEO (merged) clouds have their greatest impact on the SW down, reducing the RMS by ~50% from MODIS-only clouds. Computing (untuned and tuned) fluxes are more consistent then parameterized (model-B). Globally, tuning reduces the merged computed fluxes by 8% over untuned. The tuning of the MODIS-only clouds has a greater improvement since the clouds and fluxes are not consistent to begin with. Computing the SWup reduces the RMS error by 50% over parameterization. The LW down and LW up sees no improvement using merged over MODIS-only datasets or computation over parameterized for that matter. The greater RMS errors for LWup are due to increased biases in the LWup. Similar results are had for Terra interpolated vs. Aqua measured (not shown).

Table 8: Comparison of computed surface flux consistency between Aqua temporally interpolated and Terra measured (10:30AM)

RMS (Wm^{-2}) Aqua interpolated		**SWdown**	**SWup**	**LWdown**	**LWup**
Model B	MODIS	61	11	13	0.3
	merged	30	9	9	0.2
Untuned	MODIS	45	5	11	0.6
	merged	26	4	10	0.6
Tuned	MODIS	33	5	10	2.3
	merged	24	4	10	2.3

The consistency between diurnally computed fluxes and GERB hourly TOA measured fluxes

The GERB-2 Edition 1 level 2 products have been available since 2007. (Geostationary Earth Radiation Budget (GERB) Home Page) The GERB-2 BB instrument is on the geostationary METEOSAT-8 satellite during July 2004. The GERB instrument views the METEOSAT domain every 15 minutes and views many differing geo-types, but not the whole globe. In order to compare to the GERB TOA fluxes the calibration difference between GERB and CERES needs to be removed. Coincident CERES and GERB (within an hour) matched fluxes were used to derive the gain and offset coefficients to place GERB on the same radiometric scale as CERES. In other words the dynamic range of GERB is accurate, but maybe not the absolute calibration. The CERES absolute calibration accuracy is 1%. The GERB/CERES flux comparisons are robust enough with the global coefficients that further geo-type functionalities were not pursued. Table 8 shows the gain and offsets applied to the GERB fluxes designed to match the CERES calibration. The coefficients are similar for Aqua and Terra indicating the consistency between Terra and Aqua instrument calibrations.

Table 9: The gain and offset used to convert the GERB flux to match the CERES calibration for July 2004

	Terra		**Aqua**	
	gain	**offset**	**gain**	**offset**
SW	0.947	-9.16	0.947	-8.30
LW-day	0.966	10.85	0.996	6.10
LW-night	0.990	7.27	0.999	4.35

Figure 4 shows the MODIS-only and merged SW TOA untuned computed fluxes compared with coincident hourly GERB measured fluxes. Figure 4 clearly shows most regions see improvement using the GEO enhanced merged clouds, rather than relying on MODIS temporally interpolated clouds. Table 10 shows the TOA RMS errors between Terra based temporally interpolated TOA (observed), untuned, and tuned computed fluxes with GERB hourly measured fluxes. There is a definite improvement in the computed flux between MODIS-only and merged datasets for both SW and LW TOA fluxes. For the merged dataset the interpolated fluxes, untuned and tuned fluxes have similar RMS errors, indicating diurnal consistency between the clouds and fluxes. The tuning process improves the MODIS-only dataset since the clouds and fluxes are inconsistent to begin with.

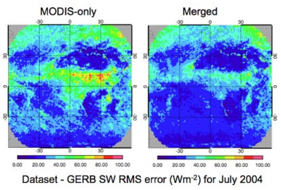

Fig 4. *Comparison plot showing the MODIS-only and Merged TOA SW untuned flux RMS error between Terra temporally interpolated and GERB hourly measured for July 2004*

Table 10: Comparison of hourly observed, untuned and tuned and GERB TOA fluxes for July 2004

Terra TOA (Wm^{-2})		**RMS (CERES-GERB)**		
		observed	**untuned**	**tuned**
SW	MODIS	43.8	33.2	32.9
	merged	27.0	27.3	26.9
LW day	MODIS	14.3	14.7	12.8
	merged	10.9	11.1	10.5
LW night	MODIS	12.8	13.3	12.2
	merged	9.0	10.9	10.2

Conclusion

In conclusion the GEO clouds, while inferior to the MODIS cloud retrievals, do improve the diurnally computed fluxes in-between MODIS measurement times. The greatest impact is in the TOA fluxes and SW down surface computed fluxes. For the surface SW up, LW down and LW up the inclusion of GEO clouds had a minimal effect. Tuning the GEO clouds to the TOA flux had little impact on the computed surface fluxes. The validation has shown that the CERES SYN/AVG/ZAVG product is the most robust computed surface flux dataset.

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